AD-A193 063 TURBULENCE STRUCTURE OF MIXING SWIRLING FLOWS(U) 1/1
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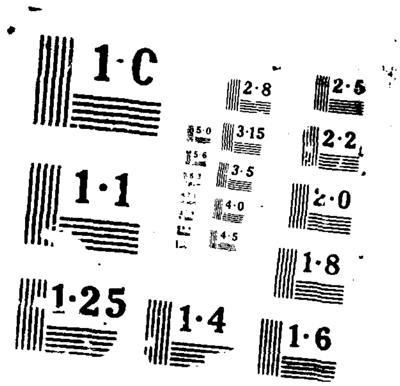
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Modifications to the swirling jet flow facilaty and mean flow data taken in the initial mixing region are described. Measurements were made at six streamwise locations downstream of the nozzel exit for three different initial mass flow rate ratios. The data were analyzed in order to calculate static pressure profiles, total and component velocity profiles, and local wall shear stress values. The results show that an axially-directed outer stream inhibits the spreading rate of the swirling inner stream and the decay of the swirl within that stream. The results also show that near-wall similarity exists in flow near the centerbody, so that the two dimensional form of the law-of -the-wall, when applied to the total velocity, can serve as a valid wall function for prediction purposes.

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Research Objectives

This study is an experimental study of co-annular jets which develop along an unconfined centerbody with swirl present in the inner stream. This situation thus corresponds to a swirling wall-bounded flow which develops in the presence of an axially directed outer flow in the absence of a streamwise pressure gradient induced by an outer bounding wall. The purpose of this study is to gain a fundamental understanding of the mixing processes which occur in a flow situation similar to that which exists in a turbofan engine where a swirling inner flow mixes with an axially directed bypass flow.

Mean flow and turbulence data will be acquired in sufficient detail so that the relative merits of various turbulence models which have been proposed for predicting swirling turbulent flows can be assessed. Some of these models are based on the use of an isotropic eddy viscosity which includes the effects of swirl in the model formulation or on the use of component eddy viscosities which do not assume isotropy.[1,2] Other models are based on algebraic Reynolds stress models which incorporate Richardson number corrections in their formulation.[3,4] From a practical point of view these models are often used in conjunction with wall functions developed specifically for two-dimensional flow which have been extended, often without sufficient justification, to a swirling flow environment.[5] An important aspect of the present study, therefore, is a critical evaluation of these models in terms of their applicability to the present flow situation.

Status of Research

Prior to initiating measurements in the swirling jet flow facility, the blow-down air supply system previously used by Mattingly and Oates[6] was replaced by a continuous flow, high-pressure fan. This modification eliminated the high noise level, intermittent mode of operation associated with the blow-down system without sacrificing the ability to run at sufficiently high Reynolds numbers for enhanced turbulent mixing. The redesign and installation of a new air supply piping system with control valves was part of this modification.

The inner and outer streams of the swirling jet flow facility exit at atmospheric pressure from two co-axial flow nozzles with induced swirl present in the inner stream. The radial width of each stream is 1 inch at the nozzle exit and the inner stream is bounded by a 4-inch diameter centerbody beyond the nozzle exit. The velocity profile of the inner stream at the nozzle exit is that of a partially developed turbulent boundary layer with a nominal swirl angle of 35° which is approximately constant across the width of the stream. The outer stream is more potential-like (spanwise uniform) across its width at the nozzle exit.

Three custom-made, subminiature pressure probes consisting of a pitot-static probe, a total pressure probe, and a Conrad probe have been used to measure the local mean-flow structure over a development length $0 \leq x/D \leq 6$ where x is the distance measured from the nozzle exit and D is the diameter of the centerbody. Data have been obtained for outer-to-inner stream mass flow rate ratios of 0,0.5, and 1.0. For these prescribed operating conditions, the local yaw angle, total pressure, and static pressure have been measured along radial traverses at six streamwise locations within the interval $0 \leq x/D \leq 6$. Local wall shear stress values have also been measured at

these locations by means of two different diameter Preston tubes. This approach presumes, of course, the existence of near-wall similarity in the mean velocity profiles, a condition which was verified when the data were plotted in terms of law-of-the-wall variables.

The radial variations in local static pressure which have been measured are in accord with anticipated behavior on the basis of streamline curvature effects induced by swirl in the flow. Over the total development length considered ($0 \leq x/D \leq 6$), the local total velocity at a fixed radial position near the centerbody increases as the mass flow rate of the outer stream is increased. This behavior occurs because the spreading rate of the inner stream is inhibited by the presence of an axially directed outer stream. Associated with this behavior is an increase in local wall shear stress levels at a given streamwise location as the outer stream mass flow rate is increased.

In the vicinity of the centerbody, the local swirl angle stays relatively constant near its initial value of 35° over the interval $0 \leq x/D \leq 3$, and then decays slowly to approximately 20° at $x/D = 6$. This behavior indicates that swirl in the near-wall layer is relatively unaffected by viscous (dissipative) effects in this region until mixing of the inner and outer streams has occurred to the extent that the wall boundary layer is influenced by the axially directed outer stream. This axially directed outer flow is also effective in suppressing the presence of swirl in the outer portion of the mixing layer.

Total velocity profiles measured near the centerbody, when plotted in terms of law-of-the-wall coordinates, show that local law-of-the-wall behavior exists at all streamwise locations within the interval $0 \leq x/D \leq 6$.

Also influencing the flow in this region is the presence of the outer stream which, as noted earlier, leads to elevated velocity and wall shear stress values at a given streamwise location. The existence of local law-of-the-wall behavior has important implications because it confirms the use of this relationship as an appropriate wall function for prediction purposes.

The above results have been supplemented recently with hot-wire measurements at the same six streamwise locations where pressure probe data were taken. For these measurements the mass flow rate ratio was unity and the first-order response model described in Ref. 7 was used to deduce local mean velocity component values. Axial and transverse mean velocity profiles measured at the last station (x/D = 6) by means of the pressure probe and hot-wire techniques are in excellent agreement. The level of agreement decreases, however, as the nozzle exit is approached, until noticeable differences in profile shape exist at the first station downstream of the nozzle exit (x/D = 0.5). At this location, turbulence levels in the mixing region are particularly high (as observed on an oscilloscope, but not yet quantified), which may have influenced the hot-wire probe readings.

In order to investigate this effect further, additional hot-wire data will be taken in the near future, and the data will be reduced by means of the second-order model described in Ref. 7. This model accounts for the effects of turbulence on calculated mean velocity values and will, hopefully, lead to improved agreement between mean velocity profiles measured by the two techniques. This conjectured behavior assumes, of course, that the pressure probe readings were not significantly influenced by high turbulence levels in the flow. If discrepancies still exist between the pressure probe and hot-wire results after the above comparisons are made, further attempts

will be made to reconcile these differences before the data are analyzed from the point of view of turbulence model assessment.

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3. Gibson, M. M., "Effects of Streamline Curvature on Turbulence," In Frontiers of Fluid Mechanics (edited by S. H. Davis and J. L. Lumley), Springer-Verlag, New York, 1984, pp. 184-198.

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6. Mattingly, J. D., and Oates, G. C., "An Experimental Investigation of the Mixing of Coannular Swirling Flows," AIAA Journal, Vol. 24, No. 5, May 1986, pp. 785-792.

7. Al-Beirutty, M. H., "Development of a Hot-Wire Technique for Moderate Intensity, Three-Dimensional Flows," PhD Thesis, Department of Mechanical Engineering, University of Washington, 1987.

Journal Publications

Although no publications based on the present study have yet appeared in a technical journal, a paper based on the hot-wire technique we have developed has been accepted for presentation at a national conference. The paper is entitled "A Hot-Wire Measurement Technique for Complex Turbulent Flows" and will be presented at the First National Fluid Dynamics Conference to be held in Cincinnati, Ohio in July 1988. An extended version of this paper will be submitted to a technical journal early in 1988.

Professional Personnel

Professor Frederick B. Gessner, Principal Investigator
Professor Robert E. Breidenthal, Co-Principal Investigator
Dr. Roger K. Nicholson, Postdoctoral Research Associate
Mr. Philip M. Dang, Research Assistant
Mr. Nicholas Fetier, Research Assistant
Mr. Mark Frey, Research Assistant

Theses Completed

1. Dang, P. M., "A Mean Flow Field Study of Coaxial Jets With Swirl Using Five-Hole Presure Probe and Hot-Wire Anemometry," MS Thesis, Department of Aeronautics and Astronautics, University of Washington, 1987.

2. Al-Beirutty, M. H., "Development of a Hot-Wire Technique for Moderate Intensity, Three-Dimensional Flows," PhD Thesis, Department of Mechanical Engineering, University of Washington, 1987.

Interactions

This project was among several projects discussed by the Principal Investigator in a presentation entitled: "Research on Complex Turbulent Flows at the University of Washington." The presentation was made to approximately 110 attendees from universities, industry, and the NASA Research Centers at the First NASA CFD Validation Workshop held at NASA-Ames in July 1987.

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